Life of the Sun—13 Oct

- Energy production in the sun
- Sun will use up the hydrogen in the center in 5Byr
- Center of sun must shrink to get hotter to balance gravity
  - Sun will become a red giant. Surface expands.
- Sun will become a planetary nebula
- Sun will become a white dwarf

Announcements

- Test 2 is Wed, Oct 20.
  - Covers material though HR diagram of star clusters (11 Oct). Does not cover energy production.
  - Covers homework 5.
  - Mostly on material since first test.
  - One cheat sheet.
  - See practice test on angel.
  - Missouri “Show me” Club
    - Tues, Oct 19, 7:40-8:40pm
    - BPS 1420
- Homework 5 is due at start of class on Mon, Oct 18. No late papers.
- Open house at the MSU Observatory
  - Friday and Saturday (October 15 and 16), 9-11pm, weather permitting
  - Bring your friends, parents, siblings, children

Proton-proton chain

- Proton-proton chain (main process in sun)
  - Step 1: Two protons fuse to produce a deuterium nucleus (^{2}H), a positive electron, and a neutrino.

    $p+p \rightarrow d+e^+ + \upsilon$
    - Deuterium is an isotope of H with one neutron.
    - A neutrino is almost massless, not charged, and interacts very weakly.

1. Did the number of nucleons change? Charge?

- Nucleons are conserved (except in some exotic interactions in the early universe).
- Charge is absolutely conserved.

Proton-proton chain

- Step 1: $p + p \rightarrow {}^2H + e^+ + \upsilon$
- In the center of the sun, a proton survives collisions without reacting for 10Byr.
  - Electrical repulsion between protons (Coulomb repulsion; Coulomb barrier)
    - Requires fast speed or high temperature to overcome repulsion.
  - Neutrino indicates a "weak" reaction, which is weak.
- Step 2: $p+{}^2H \rightarrow {}^3He+\gamma$ (Takes 6s)
  - γ is a photon, a unit of light. This photon has lots of energy.

1. In step 2, did any protons change into neutrons? Is this a weak interaction?

A. YY. B. YN. C. NY. D. NN.

Proton-proton chain

- Step 1: $p+p \rightarrow {}^2H+e^+ + \upsilon$ (Takes 10Byr)
- Step 2: $p+{}^2H \rightarrow {}^3He+\gamma$ (Takes 6s)
- Step 3: ${}^3He+{}^3He \rightarrow {}^4He+p+X$ (Takes 1Myr)

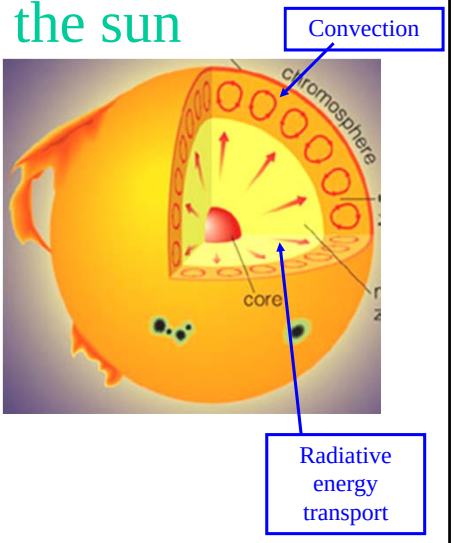
1. What is X?
   A. Neutron.
   B. Electron.
   C. Neutrino.
   D. Proton.
   E. Positron (positive electron).

Proton-proton chain

- Step 1: $p+p \rightarrow {}^2H+e^+ + \upsilon$ (Takes 10Byr)
- Step 2: $p+{}^2H \rightarrow {}^3He+\gamma$ (Takes 6s)
- Step 3: ${}^3He+{}^3He \rightarrow {}^4He+p+p$ (Takes 1Myr)
- Where is the created energy?
  - A positron meets an electron, and the two annihilate.
    - $e^+ + e^- \rightarrow 2\gamma$
  - Light interacts with matter to heat it up.
  - Moving reactants heat the matter.
  - Neutrinos escape from the sun carrying away energy.

Interior of the sun

- Use physics to construct models
- Energy is generated by nuclear fusion, which depends on temperature and composition.
- Energy moves from center, where fusion occurs, to outside, where it radiates into space.
- Gas pressure holds the mass of the parts above.



A Balancing Act

- All astronomical objects do a balancing act.
  - Gravity pulls inward.
  - Something else pushes outward.

1. The Earth does a balancing act. What prevents the Earth from collapsing?
   A. Gas pressure
   B. The strength of the materials
   C. Atoms change their directions of motion.

2. What prevents the Earth's atmosphere from being dense at my feet but sparse at my head?
   A. Gas pressure
   B. The strength of the materials
   C. Atoms change their directions of motion.

A Balancing Act: Gravity *vs*. Gas Pressure

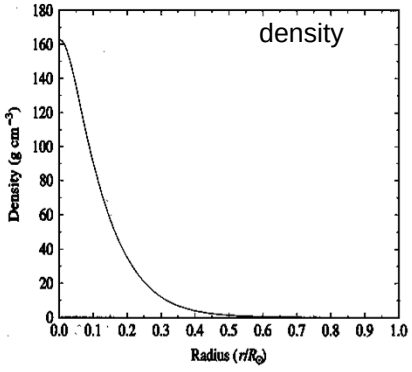
- Force of gravity balances gas pressure in the sun.
  - Force of gravity GM^2/R^2
  - Force of gas PV=nkT
    - k is Boltzmann's constant. k= R [not radius]/(number in a mole)
    - Details (m is mass of gas particle)
      P = (nm)kT/m/V=M kT/($mR^{3)}$
      F = area P = R^2 MkT/(mR^3) =M kT/(mR)
  - In balance
    $\frac{GMm}{R} = kT$
- The idea bared

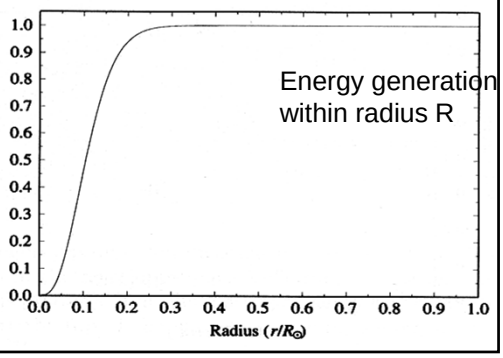
$$\frac{M}{R} = T$$

1. We are watching the birth of the sun. The not-yet sun is a gas cloud slowly shrinking. It is getting
   A. warmer
   B. cooler

Model of the Sun

1. At what radius is the density of the sun that of water (1gm/cm^3)? $0.5R_{sun}$. Same for gold (19gm/cm^3) $0.25R_{sun}$.
2. 90% of the energy is produced within $0.2R_{sun}$ of the center.





3. Why is there so much helium at the center of the sun?
   A. It used to be hydrogen.
   B. It sunk because helium is heavier than hydrogen.
   C. The heavier helium collected in the center when the sun formed.